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Genotype × Environment Interactions in Highbush Blueberry (*Vaccinium sp.* L.) Families Grown in Michigan and Oregon

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Abstract. **Twenty blueberry (*Vaccinium* sp. L.) families were planted in Michigan and Oregon to determine variability among families, locations and the importance of family × location interaction. The families were generated at Michigan State University from crosses among parents with a diverse genetic background. Seedlings were planted in field locations in Corvallis, Ore., and East Lansing, Mich., in 1995 and managed following standard commercial blueberry production practices with no insecticide or fungicide applications. In 1998–2000 the plants were evaluated for survival, bloom date, ripening date, plant growth and the fruit were scored for crop load, color, picking scar, firmness and size. All traits, except fruit color, varied significantly between locations. Plants in Oregon had a 36% greater survival rate and grew to be much larger, 80% taller and 104% wider, than those in Michigan. Families in Oregon flowered earlier in the year than those in Michigan but ripened at a similar time. Between locations, family differences were only evident for survival and fruit color. In Oregon, there were differences among families for all traits whereas in Michigan only survival, ripening date, plant height and width, and picking scar differed significantly. The family × environment interaction was not significant for crop load, fruit color and fruit firmness, so individuals selected on the basis of crop load, fruit color and fruit firmness should perform similarly in either location. There was a significant family × environment interaction for the other traits including survival, bloom date, ripening date, ripening interval, plant height and width, and for picking scar. Therefore, there is a need for individual selection programs at each location. Genotypes well adapted to Michigan may also do well in Oregon, but numerous promising genotypes could be missed for Oregon, if families are first selected in Michigan. The loss of numerous individuals due to winter cold may have reduced levels of variability in Michigan.**

The Pacific Northwest (Oregon, Washington, British Columbia) and Michigan are major commercial blueberry (*Vaccinium* sp. L.) production regions. Production in the Pacific Northwest is concentrated in the Willamette, Ore., Skagit, Wash., and Fraser River, B.C. and Wash., Valleys where the mild Mediterranean climate allows all types of blueberries to be grown. However, most of the blueberries planted in the Pacific Northwest are northern highbush cultivars, with an increasing number of rabbiteye cultivars being planted in Oregon. While much of the Michigan blueberry industry is concentrated near Lake Michigan where the climate is milder than the rest of the state, the climate there is much colder in the winter and much hotter and more humid in the summer than the Pacific Northwest. In Michigan, only northern highbush blueberry cultivars are grown.

The Pacific Northwest has relied on cultivars developed elsewhere, primarily by the USDA–New Jersey program, and while there have been some breeding efforts at Washington State University these have been small. The Michigan State University program has a long history of cultivar development; however, most of the highbush cultivars grown in Michigan were also developed by the USDA–New Jersey program.

Our study had two practical objectives. First, we wanted to determine whether there was a need to develop a breeding program in the Pacific Northwest or whether continuing to rely on blueberries developed in the eastern United States was satisfactory. A component of this for Michigan breeders was to understand which selection criteria would lead to the most broadly adapted cultivars. Second, we wanted to have a better idea of what to expect from cultivars developed in either region and planted in the other region. To address these questions, our specific objective was to evaluate variability in plant growth, phenology and reproductive characteristics in several diverse highbush blueberry families grown in Michigan and Oregon.

Few published studies have evaluated genotype and environmental variability in blueberry families and most of these have been done at a single location across years (Aalders and Hall, 1975; Edwards et al., 1974; Finn and Luby, 1986; 1992; Luby and Finn, 1986; 1987). The other studies of variability have examined genotype × environment interaction in clones in multiple years at a single location (Lyrene, 1985; Scheerens et al., 1999a, 1999b; Siefker and Hancock, 1986) or a small number of clones at several locations (Connor et al., 2002; Ehlenfeldt et al., 1995; Gupton et al., 1996; Prior et al., 1998).

Materials and Methods

Twenty crosses were made in Michigan using 11 selections that contain nine *Vaccinium* species in their background (Tables 1 and 2). The seedlings were germinated and established in plug trays in a soilless mix (peat/perlite/vermiculite) in Michigan and Oregon in 1994. In late summer 1995, seedlings from these 20 families were planted in a randomized complete block design with four 12-plant

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Table 1. Ancestry of parents used in crosses to generate families evaluated in Michigan and Oregon.

Genotype	Parent[y]	Species background (%)[z]								
		Angust	Ashei	Atroc	Const	Corym	Darr	Ell	Myrt	Myrs
US 612	G 362 x JU 64	25	---	---	---	50	---	---	---	25
US 643	US 75 x US 226	---	---	25	---	25	25	---	25	---
US 644	US 75 x US 226	---	---	25	---	25	25	---	25	---
US 645	US 75 x US 226	---	---	25	---	25	25	---	25	---
US 647	US 75 x US 226	---	---	25	---	25	25	---	25	---
US 665	G 362 x US 75	---	---	---	---	75	25	---	---	---
US 65-66	Mich 19H x Earliblue	50	---	---	---	50	---	---	---	---
US 702	G 362 x JU 64	25	---	---	---	50	---	---	---	25
US 845	US 388 x 'Cara's Choice'	---	8	---	8	25	35	25	---	---
Elliott	Burlington x US 1	---	---	---	---	100	---	---	---	---
Nelson	Bluecrop x G 107	---	---	---	---	100	---	---	---	---

[z]Abbreviations for species, Angust = *Vaccinium angustifolium* Ait.; Ashei = *V. ashei* Reade; Atroc = *V. atrococcum* (A. Gray) A.A. Heller; Const = *V. constablaei* A. Gray; Corym = *V. corymbosum* L.; Darr = *V. darrowi* Camp; Ell = *V. elliottii* Chapman; Myrt = *V. myrtilloides* Michx.; Myrs = *V. myrsinites* Lam.

[y]Scheerens et al. (1999a) was a source for much of this information.

replications at each location. The planting sites were at the USDA–ARS National Clonal Germplasm Repository's Meyer Farm in Corvallis, Ore., and the Southwest Michigan Research and Extension Station in Benton Harbor, Mich. The plants were spaced at 0.9 m within the rows and the rows were planted 3.0 m apart. Standard commercial practices for weed control, fertilization, and irrigation were followed at each location.

The Oregon site, at 44°30' N in the Willamette Valley, has a Mediterranean climate. Most precipitation (1041 mm·year^{-1}) falls between November and May with almost no summer rain. Temperatures are mild year round and during this study seldom fell more than a few degrees below freezing in the winter and were seldom above 32 °C in the summer. The Michigan site is at 42°10' N near Lake Michigan in a Continental climate. Precipitation (860 mm·year^{-1}) can occur year-round. Temperatures regularly fell below 0 °C in the winter, with lows below –20 °C, and maximum summer temperatures were generally greater than 25 °C but seldom much higher than 30 °C.

Beginning in 1998 and continuing through 2000, individual plants were subjectively scored for the following traits on a 1 to 5 scale with 1 being the poorest and 5 being the best score: vigor, crop load, fruit color, fruit picking scar, fruit firmness, and fruit size. For each of these reproductive traits, the planting was evaluated once or twice a week and, as the trait was expressed, the scores were recorded. After the plants went into dormancy each fall, the height of the tallest cane and the widest point on the bush were measured and from this the height to width ratio calculated.

Model variance components were estimated using SAS procedures (SAS Inst., 1990). Variation was partitioned into location, family, year, location × year interaction, location × family interaction, location × family × year interaction, and error.

Table 2. Mean squares and degrees of freedom for combined analysis of variance of 20 blueberry families grown in Michigan and Oregon.

Source	df	Survival	50% Bloom	30% Ripe	Ripening interval	Plant			Fruit				
						Ht (H)	Width (W)	H/W	Yield	Color	Scar	Firmness	Size
Combined													
Location (L)	1	22296.6**	10499.5**	574.2**	8754.9**	26728.1**	49827.4**	10.85**	3.56*	0.54	20.89**	3.07*	12.92**
Year (Y)	2	2.7	2425.8**	292.5**	818.4**	13645.4**	16539.0**	0.01	2.85*	2.52*	1.14*	1.18	0.96
L × Y	2	8.1	1644.7**	943.8**	1914.7**	1425.2**	2500.4**	0.07	1.31	2.65*	0.05	2.17	0.62
Replication (L,Y)	21	719.0**	56.1**	20.1	34.7*	191.2	315.1**	0.04	0.66**	0.68**	0.31	0.67**	0.59**
Family (F)	19	2520.9**	159.9	451.2	247.3	478.0	916.3	0.02	0.68	2.10**	1.20	1.01	1.05
L × F	17	1267.0**	205.8**	419.6**	194.1*	686.4*	701.8**	0.02	0.48	0.81	1.13**	0.53	1.06*
Y × F	38	24.8	55.4	54.2	58.0	40.8	61.3	0.01	0.36	0.31	0.33*	0.47	0.33
L × Y × F	34	33.8	58.4**	87.4**	68.6**	73.1	70.1	0.35**	0.30*	0.44*	0.15	0.29	0.42**
Error	273	212.3	26.5	18.0	18.7	102.6	132.0	0.11	0.16	0.22	0.19	0.23	0.18
Michigan													
Y	2	5.4	125.1	330.5**	1416.7	3536.6**	6560.0**	0.04	0.37	0.56	0.28	1.14	0.10
Replication	12	1232.6**	76.7	29.8	952.9**	223.5	486.9**	0.03	1.15*	0.59	0.35	0.79	0.74
F	17	2523.6**	144.1	605.9**	475.9	510.5**	578.7**	0.03	0.36	1.00	0.77*	0.87	0.76
Y × F	34	52.2	97.9**	113.8*	343.4	54.7	82.8	0.02	0.36	0.50	0.30	0.41	0.54
Error	106	486.5	43.0	47.8	260.2	130.7	174.1	0.03	0.44	0.54	0.23	0.40	0.44
Oregon													
Y	2	3.7	18004.4**	3094.1**	17355.5**	33544.6**	28412.0**	0.27**	21.89*	15.84**	2.33**	2.35*	7.48**
Replication	9	34.3	28.6	8.2	40.4*	148.2	86.1	0.01**	0.06	0.80**	0.24	0.50**	0.39**
F	19	1368.4**	248.0**	268.2**	93.8*	678.9**	1068.8**	0.08**	0.94**	2.48**	1.58**	0.90*	1.93**
Y × F	38	2.1	18.1	22.8**	41.8**	64.2	47.0	0.00	0.33**	0.21*	0.26	0.38**	0.19*
Error	167	38.2	19.9	11.4	18.7	85.0	105.7	0.00	0.10	0.14	0.18	0.18	0.11

*,**Significant at $p < 0.05$ and 0.01, respectively.

Results and Discussion

All traits, except fruit color, varied significantly across locations (Table 2). The plants in Oregon had a 36% greater survival rate and grew to be much larger plants, 80% taller and 104% wider, than those plants grown in Michigan (Table 3). The height/width ratio was ≈15% greater in Michigan and approached a 1:1 ratio whereas the plants in Oregon tended to be wider relative to their height. Plants flowered nearly three weeks earlier in Oregon than they did in Michigan but the average ripening dates, while significantly different, were less than two days apart. Subsequently, the bloom to ripening interval was 20 d shorter in Michigan than Oregon. The families in Oregon had larger crops and better (smaller and/or drier) picking scars, while those from Michigan had firmer and larger fruit. The differences among fruit quality scores must be interpreted cautiously as they were subjective, used a categorical form of scoring with a limited number of categories (five), and the scorings were done by different people in each location. Marked differences between locations in terms of year and family effects could be due in part to individuals in one location using the range of categories more widely than individuals in the other locations.

All traits except fruit firmness and height/width ratio, varied significantly across years (Table 2). This was expected for the phenological traits, growth measurements and crop load estimates, as these are age dependent traits or tied very closely to heat unit accumulation, which varies annually. Fruit color was scored highest in 1999 and fruit firmness scores declined each year (Table 3). We were unable to identify environmental trends common to both sites that might account for this variability.

Family differences were only evident across locations for vigor/survival and fruit color (Table 2). Within locations, there were significant differences among families for all traits in Oregon (Table 4) and for vigor and survival, ripening date, plant height and width, and picking scar in Michigan (Table 5). The family × location interactions were significant for survival, bloom date, ripening date, ripening interval, plant height and width, and for picking scar (Table 2). In most cases, the mean squares for the location × family interaction were similar to or larger than those for families (Table 2) suggesting that a breeding program in each location may be important.

In Oregon, few plants were lost after establishment and the plants grew rapidly (Table 4). This was not the case in Michigan, however, where large family differences were seen in survival and the plants were much more slow growing (Table 5). Plant survival in Michigan ranged from 0% to 78% and five families had less than 50% survival. Families US 643 x US 644 and US 645 x US 702 did not survive at all in Michigan and families US 702 x US 65-66 and 'Nelson' x US 643 had <60% survival (Tables 3 and 5). In Oregon, all but five families had 90% or greater survival and the lone low vigor family

Table 3. Mean values for 12 traits for 20 blueberry families grown in Michigan and Oregon and evaluated in 1998–2000.

				Ripening	Plant							
	Survival	50%	30%	interval	Ht (H)	Width (W)	H/W	Fruit[y]				
Source	(%)	Bloom[z]	Ripe[z]	(days)	(cm)	(cm)	ratio	Yield	Color	Scar	Firmness	Size
Location												
Michigan	56.0	134.3	195.8	61.5	42.7	46.1	0.97	2.0	3.0	2.7	3.9	3.6
Oregon	92.4	112.8	194.5	81.7	77.3	94.4	0.82	2.2	3.0	3.7	3.6	2.5
Year												
1998	77.8	106.5	193.3	86.8	44.6	55.2	0.87	1.7	2.4	3.7	3.9	2.3
1999	76.9	128.1	199.0	70.8	64.1	75.1	0.88	1.9	3.3	3.6	3.6	2.9
2000	76.5	125.7	192.5	66.8	80.0	92.4	0.88	2.5	2.9	3.1	3.6	3.0
Family												
US 612 x US 647	77.8	125.7	199.5	73.7	60.6	66.6	0.92	2.0	3.2	3.4	4.1	2.9
US 612 x US 65-66	78.1	126.5	202.6	76.1	52.2	58.5	0.93	2.1	2.9	3.4	3.9	3.2
US 612 x US 845	88.9	122.4	204.6	82.2	67.1	82.5	0.85	2.4	2.7	3.1	4.1	2.8
US 643 x US 644	100.0	105.5	189.5	84.0	87.3	102.5	0.85	1.5	2.7	2.5	3.0	2.2
US 643 x US 65-66	81.4	114.3	183.5	69.2	63.5	78.5	0.83	2.1	2.5	2.9	3.5	2.8
US 643 x US 702	82.1	115.7	188.6	73.0	62.9	81.1	0.83	2.0	1.8	3.0	3.3	2.1
US 644 x US 702	72.6	120.0	193.4	73.4	58.1	70.4	0.86	2.1	2.5	3.5	3.6	2.5
US 645 x US 702	57.9	116.8	192.6	75.8	56.5	70.1	0.84	1.8	2.7	3.8	3.9	2.5
US 647 x US 65-66	64.3	117.7	189.0	71.3	54.4	58.4	0.95	2.0	3.3	3.7	3.4	2.8
US 647 x US 845	79.2	126.2	195.9	69.7	62.6	73.0	0.92	2.0	3.3	3.4	3.6	2.7
665 x US 702	89.3	120.6	192.6	71.9	61.6	75.2	0.84	2.0	2.8	3.2	3.4	3.0
665 x US 845	86.9	124.4	197.9	73.5	67.1	81.1	0.88	2.3	3.2	3.5	4.1	2.8
US 702 x US 65-66	79.2	110.5	187.7	77.2	69.3	92.0	0.75	2.1	2.7	4.3	3.9	2.2
US 845 x US 65-66	75.0	119.7	191.8	72.0	62.6	78.5	0.82	2.5	3.2	3.7	4.0	2.8
Elliott x US 612	83.8	120.5	198.9	78.4	62.7	77.7	0.82	2.4	2.8	3.6	3.4	2.9
Elliott x US 647	73.6	122.5	198.8	76.3	61.2	63.4	0.98	2.1	4.0	3.5	3.6	3.5
Elliott x US 65-66	65.4	118.9	197.4	78.5	60.0	66.0	0.94	2.5	3.4	3.4	3.3	3.3
Elliott x US 702	75.9	121.4	199.6	78.2	59.5	81.2	0.76	2.0	2.6	3.6	3.6	2.9
Nelson x US 643	46.1	122.7	188.2	65.6	71.2	69.5	1.02	1.9	3.2	2.7	3.0	3.1
Nelson x US 845	88.9	124.5	193.7	69.2	72.6	80.1	0.91	2.0	3.3	3.5	3.8	2.9
Mean	77.0	120.5	194.9	74.4	62.8	74.1	0.88	2.1	3.0	3.4	3.7	2.8
Standard error	1.30	0.84	0.58	1.11	1.28	1.57	0.01	0.04	0.05	0.05	0.04	0.05

[z]Days from 1 Jan.
[y]Scores on a 1 to 5 scale with 1 being the poorest expression of the trait and 5 being the best.

was 'Nelson' x US 643 (Table 4). Interestingly, the families derived from US 845, which is 75% southern species in origin, generally survived well in Michigan (Table 5). While some plants were killed outright in Michigan, many others had damaged shoot tips resulting in poor plant growth.

The genotype × environment interactions for survival and plant growth confirmed our observations in commercial blueberry fields. Oregon has a mild climate and the USDA-ARS National Clonal Germplasm Repository *Vaccinium* collection was sited here in part because under such a climate all North American *Vaccinium* can grow well here. Severe killing winter temperatures are seldom experienced and the combination of cool spring and summer nights and warm days with high light intensity is an optimal environment for blueberry growth. While northern highbush blueberries are generally well adapted to Michigan, winter hardiness is an annual concern.

The families in Oregon with a late ripening cultivar (Nelson or Elliott) as parent were generally the latest flowering and ripening families, as were several of the families with US 845 as a parent (Table 4). However, one of these late flowering families, 'Nelson' x US 643, had the shortest ripening interval. A genotype × environment interaction was not surprising for bloom date as the springtime climates are very different in the two environments (Table 2). In Oregon, gradually rising late winter and early spring temperatures allow budbreak to occur much earlier than they do in Michigan where the appropriate temperatures for budbreak occur much more abruptly. As a result, all but one of the Michigan families bloomed within 10 d of one another, whereas in Oregon the range was 15 d (Tables 4 and 5). Probably due to these environmental differences, the families derived from 'Elliott' and 'Nelson' bloomed later than the other families in Oregon, whereas they were among the earliest blooming in Michigan. Ripening dates in Michigan tended to be latest in families with US 612 as a parent. (Table 5). The families derived from US 65-66, which is 50% *V. angustifolium*, were consistently early ripening in Oregon whereas in Michigan they ranged from very early to very late (Tables 4 and 5). Similarly, families from the late ripening cultivars Elliott and Nelson, were nearly all very late ripening in Oregon and were near average or slightly earlier in Michigan. The bloom to ripening interval was 20 d longer in Oregon than Michigan but no trends were apparent in how the families responded to these different environments.

Fruit color varied widely among families with family 'Elliott' x US 647 having the best fruit color at both locations and the families derived from US 643 and US 644 tending to have poor fruit color (Tables 2 and 3). Even though there was not a significant family × location interaction for picking scar, family US 643 x US 65-66 and 'Nelson' x US 643, both US 643 derivatives, had two of the poorest, and family 'Elliott' x US 647 had among the best picking scar scores at each location. Differences among families for fruit firmness were only evident at the Oregon location (Table 4) although family 'Nelson' x US 643 was among the poorest for fruit firmness at both locations (Tables 4 and 5). Fruit size had a significant genotype × location interaction with many families scoring well in one location but not the other. This may reflect the differences in ripening conditions at each location. Michigan is much hotter during the ripening stage. There was very little variation

Table 4. Mean values for 12 traits for 20 blueberry families grown in Oregon and evaluated in 1998–2000.

				Ripening	Plant							
	Survival	50%	30%	interval	Ht (H)	Width (W)	H/W	Fruit[y]				
Source	(%)	Bloom[z]	Ripe[z]	(days)	(cm)	(cm)	ratio	Yield	Color	Scar	Firmness	Size
Year												
1998	92.9	95.2	193.9	98.4	54.0	72.7	0.75	1.6	2.2	3.9	3.8	2.0
1999	92.1	122.7	201.1	78.6	83.4	101.0	0.83	2.1	3.3	3.8	3.4	2.6
2000	92.2	120.2	188.5	68.3	94.4	109.1	0.87	2.7	3.0	3.5	3.6	2.7
Family												
US 612 x US 647	89.6	110.8	195.5	84.7	70.8	78.2	0.90	2.1	3.2	4.0	3.8	2.3
US 612 x US 65-66	100.0	106.0	189.4	83.5	68.9	81.3	0.84	2.2	2.6	4.2	3.4	2.6
US 612 x US 845	100.0	114.9	197.2	82.4	80.1	105.0	0.76	2.8	2.8	3.9	4.1	2.0
US 643 x US 644	100.0	105.5	189.5	80.0	87.3	102.5	0.85	1.5	2.7	2.5	3.0	2.2
US 643 x US 65-66	100.0	106.2	185.0	78.8	89.1	110.2	0.80	2.2	2.7	3.1	3.2	3.0
US 643 x US 702	97.9	108.1	189.5	81.4	73.9	101.6	0.72	1.9	1.5	3.2	3.4	1.8
US 644 x US 702	83.3	109.3	193.7	83.0	66.1	87.4	0.75	2.0	2.6	4.0	3.6	2.0
US 645 x US 702	79.2	109.2	193.2	84.0	67.2	84.9	0.79	1.8	2.6	4.2	3.9	2.1
US 647 x US 65-66	97.9	109.5	190.0	80.5	79.0	84.5	0.93	2.0	3.3	4.0	3.4	2.9
US 647 x US 845	99.3	119.0	196.1	77.1	83.7	103.7	0.80	2.1	3.1	3.6	3.6	2.2
665 x US 702	100.0	110.7	195.9	85.2	75.9	96.1	0.78	2.2	2.8	3.9	3.5	2.4
665 x US 845	97.9	116.0	198.3	82.3	82.6	107.2	0.76	2.3	3.1	3.8	4.1	2.3
US 702 x US 65-66	79.2	110.5	187.7	77.2	69.3	92.0	0.75	2.1	2.7	4.3	3.9	2.2
US 845 x US 65-66	97.9	112.5	192.8	80.2	81.4	105.2	0.77	2.6	3.3	4.1	3.9	2.4
Elliott x US 612	95.8	116.9	199.8	83.0	75.8	94.6	0.79	2.5	2.8	3.7	3.4	2.7
Elliott x US 647	96.5	117.9	203.1	85.2	79.0	83.4	0.94	2.1	3.9	3.5	3.2	3.3
Elliott x US 65-66	95.1	115.7	198.2	82.4	80.7	90.1	0.89	2.4	3.5	3.5	3.2	3.3
Elliott x US 702	81.3	116.9	201.0	84.0	63.8	94.0	0.67	2.1	2.7	4.0	3.6	2.7
Nelson x US 643	57.6	119.7	193.0	72.1	89.3	86.6	1.03	2.1	3.1	2.8	3.0	3.0
Nelson x US 845	98.6	119.6	198.7	79.1	83.0	94.2	0.87	2.1	3.5	3.8	3.8	2.7
Mean	92.4	112.8	194.5	81.4	77.3	94.4	0.82	2.2	3.0	3.7	3.6	2.5
Standard error	0.77	0.90	0.52	0.89	1.34	1.33	0.01	0.04	0.05	0.04	0.04	0.04

[z]Days from 1 Jan.
[y]Scores on a 1 to 5 scale with 1 being the poorest expression of the trait and 5 being the best.

Table 5. Mean values for 12 traits for 20 blueberry families grown in Michigan and evaluated in 1998–2000.

Source	Survival (%)	50% Bloom[z]	30% Ripe[z]	Ripening interval (days)	Plant Ht (H) (cm)	Plant Width (W) (cm)	Plant H/W ratio	Fruit[y] Yield	Fruit[y] Color	Fruit[y] Scar	Fruit[y] Firmness	Fruit[y] Size
Year												
1998	57.3	129.6	189.8	60.1	32.0	31.7	1.04	2.0	3.2	2.9	4.1	3.5
1999	56.2	137.4	192.6	55.2	38.2	40.3	0.96	1.4	3.3	2.9	4.1	3.7
2000	54.3	134.9	199.3	64.4	59.1	67.8	0.89	2.3	2.8	2.5	3.7	3.6
Family												
US 612 x US 647	62.0	148.1	207.3	59.2	46.9	51.1	0.95	2.0	3.0	2.4	4.5	4.1
US 612 x US 65-66	65.0	138.8	212.4	73.6	41.4	43.9	0.98	2.1	3.0	2.9	4.2	3.6
US 612 x US 845	77.8	132.4	215.6	83.2	54.0	60.0	0.94	1.7	2.6	2.1	4.1	3.9
US 643 x US 644	0	---	---	---	---	---	---	---	---	---	---	---
US 643 x US 65-66	59.2	130.4	177.3	46.9	32.6	40.4	0.86	1.7	2.0	2.3	4.3	2.3
US 643 x US 702	61.1	128.6	185.3	56.6	48.4	53.8	0.98	2.1	2.7	2.4	3.0	3.2
US 644 x US 702	58.3	134.2	192.6	58.4	47.4	47.6	1.01	2.2	2.3	2.4	3.7	3.7
US 645 x US 702	29.6	135.0	190.1	55.1	42.2	50.4	0.91	2.1	3.1	2.6	3.9	4.1
US 647 x US 65-66	33.3	131.9	183.0	51.1	31.7	34.2	0.98	2.0	3.5	2.5	3.5	2.5
US 647 x US 845	59.0	135.7	195.4	59.7	41.5	42.3	1.04	1.8	3.6	2.9	3.4	3.3
665 x US 702	75.0	133.8	186.9	53.0	42.7	47.3	0.92	1.8	2.7	2.4	3.4	3.8
665 x US 845	72.2	135.5	196.6	61.0	46.5	46.2	1.05	2.0	3.6	2.6	4.1	4.1
US 702 x US 65-66	0	---	---	---	---	---	---	---	---	---	---	---
US 845 x US 65-66	44.4	132.1	188.8	56.7	37.6	42.8	0.89	2.1	2.8	2.6	4.3	3.9
Elliott x US 612	59.7	135.2	193.1	58.0	36.6	44.0	0.87	1.9	2.9	3.0	3.7	3.6
Elliott x US 647	50.7	131.8	190.2	58.4	41.7	41.6	1.04	2.1	4.3	3.7	4.3	3.9
Elliott x US 65-66	20.8	131.5	192.5	61.0	28.8	29.8	1.00	2.8	3.0	2.8	4.0	3.3
Elliott x US 702	65.3	130.3	195.4	65.1	51.0	55.8	0.92	1.8	2.3	2.4	3.8	3.5
Nelson x US 643	25.0	128.1	177.5	49.4	41.1	41.0	1.02	1.4	3.2	2.6	2.8	3.2
Nelson x US 845	75.9	132.9	183.6	50.7	58.7	61.4	0.97	1.9	3.0	2.9	3.8	3.1
Mean	56.0	134.3	195.8	61.5	42.7	46.1	0.97	2.0	3.0	2.7	3.9	3.6
Standard error	1.99	0.80	1.60	2.60	1.31	1.63	0.01	0.08	0.10	0.07	0.08	0.08

[z]Days from 1 Jan.
[y]Scores on a 1 to 5 scale with 1 being the poorest expression of the trait and 5 being the best.

in crop load in Michigan, but in Oregon, families US 612 x US 845, 'Elliott' x US 612, and 'Elliott' x US 647 had the greatest crop load. Across both locations, the families derived from US 702 frequently had low scores for fruit quality traits, but this trend was not obvious for its full sib US 612 (Table 3).

Conclusions

Results of this study suggests that there is a need for individual selection programs in Oregon and Michigan. While individuals selected on the basis of crop load, fruit color and fruit firmness should perform similarly in either climate, there was a significant family × environment location interaction for the other eight traits and these were often much larger than those due to family alone. In Oregon, there were significant differences among families for all traits evaluated, whereas in Michigan there were differences among families for only half of the traits. Genotypes well adapted to Michigan may also do well in Oregon, but numerous promising genotypes could be missed for Oregon, if families are only selected in Michigan. The loss of numerous individuals due to winter cold may have reduced variability in Michigan.

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